A STUDY ON THE MECHANICAL PROPERTIES OF CAR PANELS STRAIGHTENED BY FOUR METHODS

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Current increase in car numbers leads to higher probability for traffic incidents. Car panels damaged in collisions on small to moderate scale can be repaired by straightening by cold working and heating. The aim of the research was to find how repairing changes the mechanical behavior of the mechanical behavior and characteristics of a mild steel used for panel manufacture. Four repair methods: hammering, using a spot weld puller and heating using two heat sources (flame and induction heating) were applied on crash damaged car panels from which specimens for mechanical tests in tension, compression and bending were obtained and tested.

The results showed that, from a mechanical perspective, hammering repairs yield the closest results to the original steel with good repeatability and reproducibility.

Keywords: car panel, straightening, mechanical behavior, mechanical properties

1. Introduction

In 2020 the global auto industry expects a sale number of 74 million units [1] and as the number of cars increases so does the number of road accidents. Statistics show that up to 80% of damages resulted in collisions are of small and medium scale [2] of which up to 50% do not require part replacement.

Post impact the damage can be classified as direct damage (Fig. 1), that is visible (gouges, tears, scratches), indirect damage, caused by collision and inertial forces (more difficult to identify and repair) and a work hardened region created by impact [3]. Repairing the damaged area has become a common practice whenever possible by straightening.

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Fig. 1 Apparent damage that can be repaired by straightening

A panel is a car body part made of plastic or metal (such as fenders, hoods, roof panels) that once involved in an impact can be either replaced or straightened. Metal panel straightening is performed with a set of tools and equipment that forces it back to its original shape

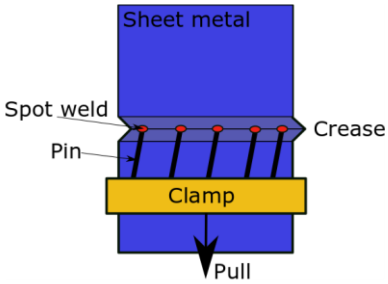


Fig. 2 Straightening procedure with spot weld pullers

Common panel straightening methods employ hammers, dollies, spoons, suction cups, dent pullers and spot weld pullers that mend the defect by cold working and metals shrinking and stress relieving using heat [4].

Spot weld pullers are devices that are used to remove dents by spot welding pins or a tip that allows the sheet metal to be pulled from the exterior [4], a schematic of the procedure is shown in Fig. 2. Before the spot welder holes were drilled and using screws or hooks the same procedure was performed then the holes welded shut.

Metal shrinking is performed with a heat source (gas torch, electric welder, by induction shown in Fig. 3) on small regions, on the highest spot of the deformed panel, and repeated until the sheet metal has shrunk back to its proper position [4].

All these procedures can be used individually or in association, depending on the extent of damage. A general procedure from repair shops includes:

Fig. 3 Metal shrinking using induction heating

- removal of moldings, emblems inserts and other material behind the panels
- rough repairs of dents by hammer or puller
- finishing with hammer and dolly
- panel shrinking (if required)
- straightening small dents

- completion of repairs (using filler, filling, sanding, priming, rust proofing, painting etc.).

Structural safety features such as crash zones are included in modern cars and their design and performance are based upon specific material characteristics that are altered when straightened. In general, the processing techniques modify the materials structure and consequently their final properties [5, 6, 7].

Performing above mentioned operations clearly alters the structure and properties of the material and in which extent was the aim of this study [8, 9].

Using straightened car panels by most employed methods tensile, compression and bending specimens were obtained, tested and compared with samples obtained from an original panel to determine how the straightened material behaves and compare it with its initial state.

2. Materials and methods

The materials used for the current experiment were obtained directly from panels that were deformed by collisions and straightened using repair-shop methods: one panel was straightening by hammering, another two by heating using the flame method and by induction and the fourth by using the "spotter" method.

The panels used in the test were obtained from cars that suffered similar impacts and were of the same type. For reference an original panel was used.

In table 1 sample coding and repair procedures applied for each sample set are presented.

Table 1

Sample coding and straightening methods employed

Sample Code	Straightening procedure
P1	None, original panel
P2	Straightened by hammering at room temperature
P3	Straightened using flame heating
P4	Straightened using induction heating
P5	Straightened using a spot weld puller

From each of the five body panels samples were cut for mechanical tests according to standard specifications as well for microstructure investigations.

The chemical composition was determined using an optical emission spectrometer SPECTROMAXx. Light microscopy studies were performed using a Reichert UnivaR microscope. Vickers hardness tests were performed using a CV Instruments hardness tester and tensile, compressive and flexural tests were performed using a Walter+Bai LFV 300 universal testing machine. Fracture morphology was studied using an Olympus SZX7 stereomicroscope.

3. Results and discussion

3.1 Chemical composition of the alloy

On each panel the chemical composition was determined by optical emission spectroscopy by performing 5 measurements in distinct locations. Since all body panels were made by the same producer and stemmed from the same type of care, it was expected that the same alloy was used. In table 2 the average values in weight percent are presented.

Table 2

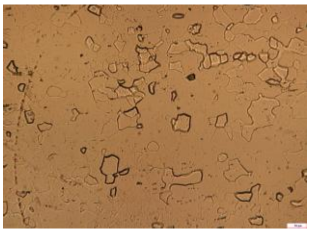
Chemical composition of the steel (%wt)

%C	%Si	%Mn	%P	%S	%Cr	%Fe
0.054	0.12	0.38	0.015	0.007	0.037	Bal.

According to the chemical composition the alloy is a steel from the large group of non alloyed quality steels. Its chemical composition best matches to 1.0035/S185 steel according to DIN 1615(10/1984) and DIN EN 10025(03/1994), E185 according to ISO 630(1995) and OL32.1 according to Romanian STAS 500/2(1988).

3.2 Light microscopy

Light microscopy studies performed on the metallographic prepared specimens on longitudinal directions revealed a ferritic microstructure with tertiary cementite on grain boundaries, as seen in Fig. 4.a to e.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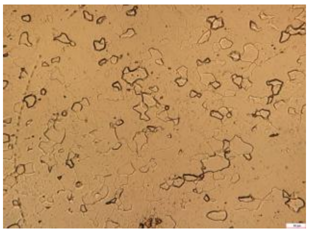
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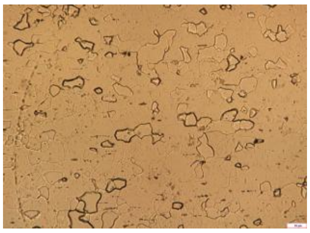
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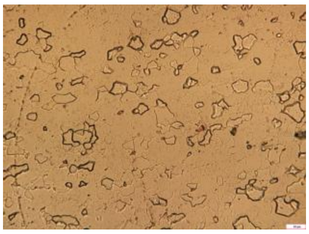
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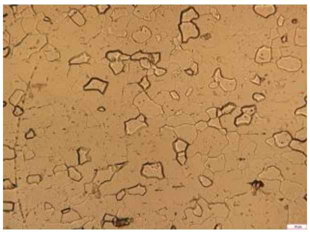

e.

Fig. 4 Light microscopy micrographs showing the microstructure for a. sample P1, b. sample P2, c. Sample P3, d. Sample P4 and e. Sample P5.

A slight grain orientation can be observed for samples P1, P2 and P5 depicted in Fig. 2.a, b and e, suggesting that the steel is cold rolled. Although the samples were heated by flame and an inductor the process parameters were optimized following a previous study [10] and the grain size remained unchanged. A slight grain size increase can be inferred for sample P3 and P4, as depicted by Fig. 4.c and 2.d, but barely noticeable.

3.3 Vickers hardness tests

The Vickers hardness tests were performed according to *ISO 6507-1:2018 "Metallic materials - Vickers hardness test - Part1: Test method"* using a load of 200gf with a holding time of 30sec. The tests were performed on metallographic prepared specimens on a transverse direction.

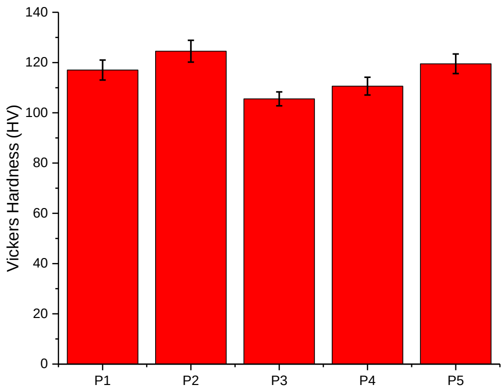


Fig. 5 Average Vickers hardness values for tested specimens

On each specimens 5 tests were performed, in Fig. 5 the averaged value ± 1 standard deviation are presented.

The reference specimen P1 yielded an average value of 117HV, while by cold working a slight increase was observed, up to 125HV for sample P2. The heated specimens showed a lower micro hardness value, 106HV for sample P3 and 111HV for sample P4, the heating acting similar to a low temperature annealing.

The average hardness value of sample P5 was approximately 120HV, similar to the reference specimen P1. Given the procedure of straightening using the spotter, no significant deviation from the reference sample P1 was expected.

3.4 Tensile testing

Tensile testing was performed according to *ISO 6892-1:2016 "Metallic materials - Tensile testing - Part 1: Method of test at room temperature"* on a Walter+Bai LFV 300 universal testing machine using five specimens obtained from each body panel.

The dimensions and geometry of the samples used were also according to standard specifications.

In Fig. 6 a selection of stress-strain curves is depicted where a ductile behavior can be observed.

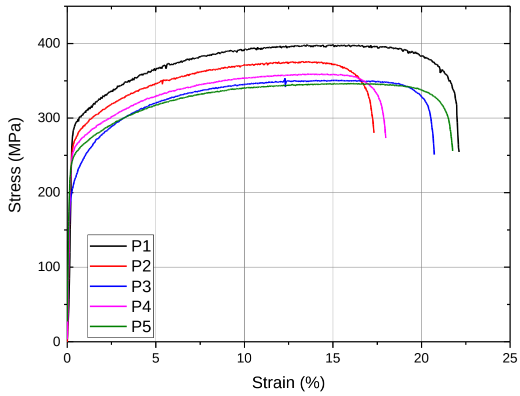


Fig. 6 Stress-strain curves for a sample from each condition

Processing the curves the yield and tensile strengths, elongation after fracture and percentage reduction in area were determined. Averaged values ±1 standard deviation are presented, for comparison, in Fig. 7.

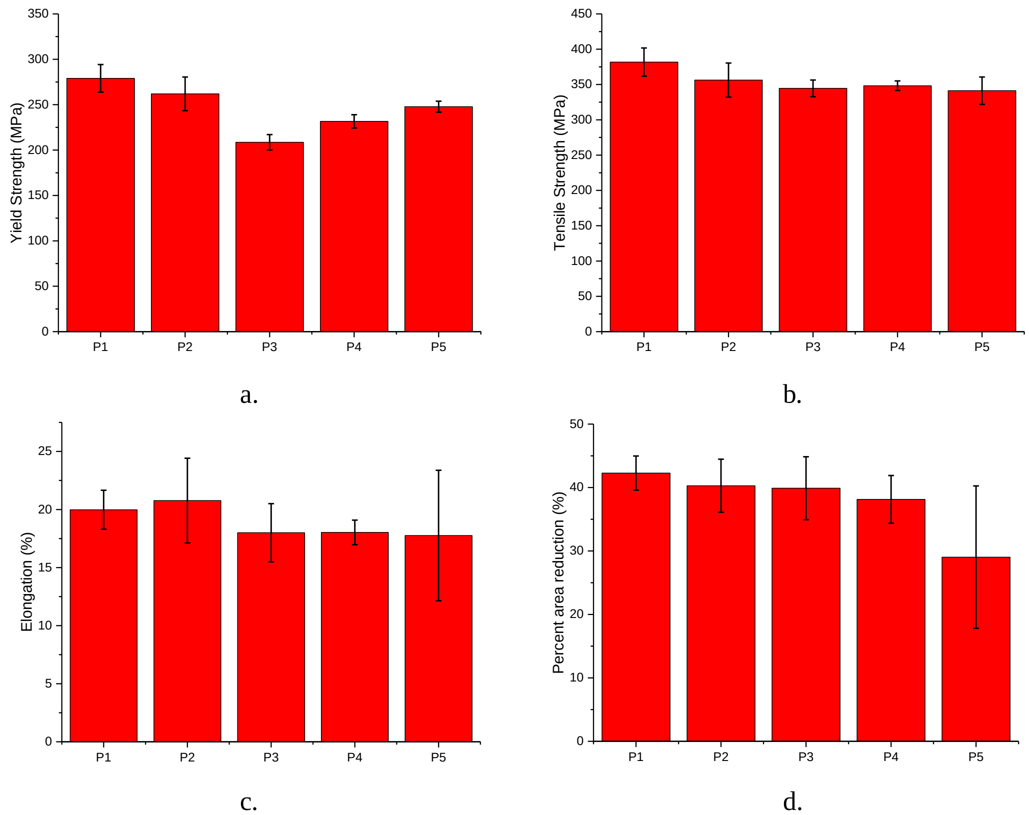


Fig. 7 Comparison of average values for a. yield and b. tensile strengths, c. elongation at fracture and d. reduction in area

According to standard specifications for steel 1.0035 the minimum yield stress should be 185MPa. By comparing the yield strengths as presented in Fig. 7.a it was observed that the reference sample P1 has the highest value while the flame heated sample P3 has the lowest value. The cold worked sample P2 showed lower values than the reference sample P1 because localized deformations were induced by hammering and, given the non-uniform stresses and strains failure occurred prematurely [8, 11]. Between heated samples it was observed that P4 has higher yield strength than P3 suggesting that the highest temperature reached was lower when heating by induction [12, 13, 14].

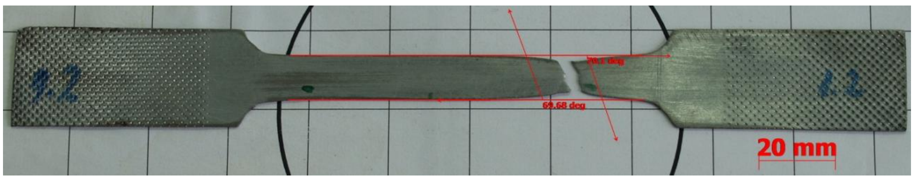
Although obvious changes in the values of the yield strength were observed post straightening, its value was higher than that specified by standards.

The tensile strength of 1.0035 should be at least 310MPa according to standard specifications and in this case, as depicted in Fig. 7.b, it shows a decreasing trend from sample P1 to sample P5. In a previous study [15] it was stated the tensile strength is not a good descriptor for the mechanical properties given the non uniform strains which occur in the test sample, yet this value did not fall below standard specifications.

In Fig. 7.c it can be seen that the elongation at fracture appears to be highest for the P2 sample. Despite straightening all direct damage, small bents and creases still remained which straightened during the test. The high spread of the results is a consequence of this behavior [16]. From Fig. 7.d one can see that the percent area reduction shows a descending trend starting from P1 with highest value. Highest data spread was observed for sample P5.

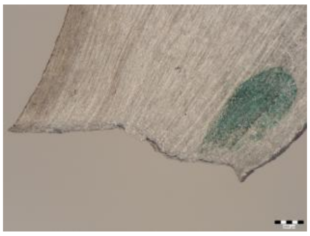
When straightening by heating is performed regions in the sheet metal are heated above critical temperatures and microstructure change occurs consequently in this regions mechanical properties vary and the strain distribution is not uniform [10, 15], the heated regions (where mechanical characteristics are lowest) are strained strongest and failure is most likely to occur at these regions [17]. This behavior can explain why heated samples show lower elongations and percentage reduction in area than the reference specimens, as Fig. 7.c and d show.

These conclusions are supported by a fractographic analysis of the failed specimens; in following paragraphs a selected sample from each group is presented. In Fig. 8 a. a failed specimen from the P1 set is shown where uniform strains are observed until the necked region.



a.


b.


c.


d.


e.

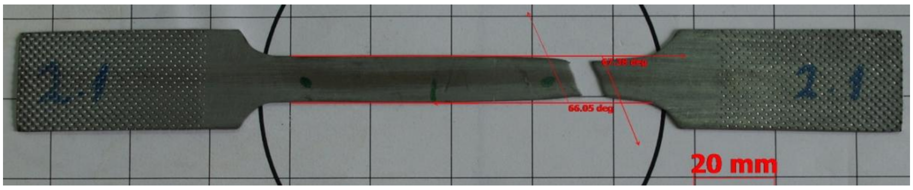
Fig.8 Failed specimen from P1 group showing a. view of the failed tensile specimen, b. and c. details from the fracture region, d. and e. material deformation in the calibrated length

The fracture occurs at an angle of approximately 70° in respect to the long axis with significant necking before fracture, as seen in Fig. 8 b. and c.

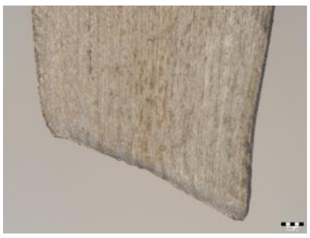
The material flow in the calibrated length of the specimen, observable in Fig. 8.d and e., appears uniform and parallel with the loading direction.

The tensile specimen was strained in an uniform manner on its entire length until necking occurred and strong and localized deformations were observed solely in this region.

The generic appearance of failed tensile specimen from the P2 group is shown in Fig. 9 a. and apparently the strains are also uniform until the necked region.



a.

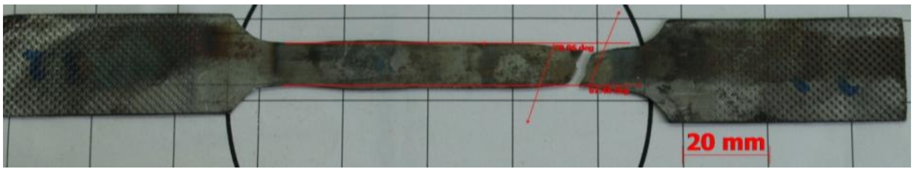

b.


c.

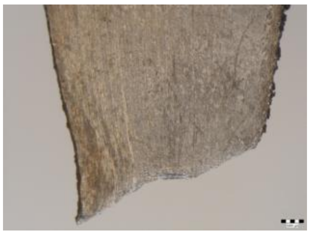
Fig. 9 Failed specimen from P2 group showing a. failed tensile specimen appearance, b. and c. details from the fracture region

The fracture occurs at an angle of approximately 67° in respect to the long axis of the tensile specimen, similar to the reference specimens.

Although the panel straightened by cold working shows a behavior similar to the reference one, at the fracture site shown in Fig. 9 b. and c. some regions are more deformed. In Fig. 10 a. the appearance of sample from P3 set is shown and non uniform deformations are clearly observable in the calibrated length region.



a.



b.

c.

d.

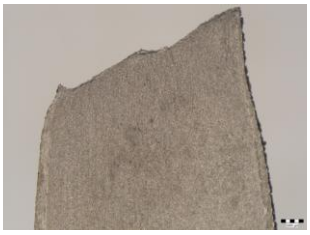
e.

Fig. 10 Failed specimen from P3 group showing a. the appearance of the failed specimen, b. and c. details from the fracture region, d. and e. material flow in the calibrated length

The fracture occurs at an angle of approximately 69° in respect to the long axis of the tensile specimen with accentuated necking as shown in Fig. 10 b. and c. The strains are not uniform in the sample, the material flow in the calibrated length of the tensile specimen can be observed in Fig. 10 d. and e.

A fractured tensile specimen from the P4 set is presented in fig. 11.a where non uniform strain distribution can be observed.

a.


b.

c.

d.

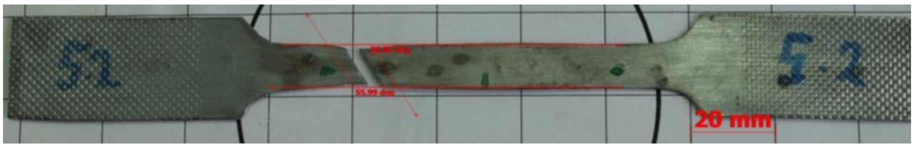
e.

Fig. 11 Failed specimen from P4 group showing a. failed tensile specimen appearance, b. and c. details from fracture region, d. and e. material flow in the calibrated length

Given the low area of the induction heating source smaller regions with non uniform deformations can be observed in comparison to specimens heated using the flame.

Fracture appears at an angle of approximately 42° in respect to the long axis of the tensile specimen with a less pronounced necking, as depicted by Fig. 11 b. and c. Deformations are not uniform in the specimens, as illustrated in Fig. 11 d. and e.

In Fig. 12 a. a fractured tensile specimen from set P5 is presented, showing relative uniform deformations.



a.

b.

c.

d.

e.

Fig. 12 Failed specimen from P5 group showing a. failed tensile specimen appearance, b. and c. details from fracture region, d. and e. material flow near a spot weld created with the spotter

The fracture occurs at an angle of approximately 56° in respect to the long axis of the specimen, and the necking is least of the entire set, as presented in Fig. 12 b. and c.

The spot weld points on the surface change drastically how the material behaves in tension [18, 19], details on material flow in these regions is presented in Fig. 12 d. and e. Fracture occurred mostly on the vicinity of such weld spots, as shown in Fig. 12 c.

Given the wide data spread and material flow, using the spotter method for straightening yields most unpredictable material behavior.

3.5 Compression testing - the RAE method

This test used as guide a test method proposed by Royal Airforce Establishment (RAE) from the United Kingdom for assessing the compression behavior of unidirectional composites.

This testing method was adopted given that it mimics, in a large extent, the compressive loads that occur in a frontal impact of the car in an attempt to study the material behavior.

The test assembly is depicted in Fig. 13: two steel blocks with a central notch for the test sample were adapted to the tensile testing machine gripping device and an uniform axial compression load was applied parallel to the long axis of the specimen.

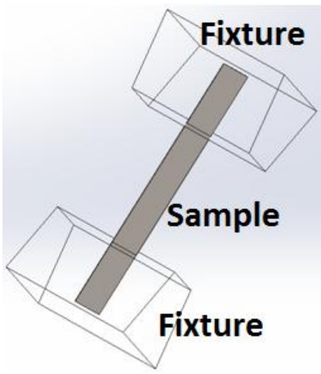
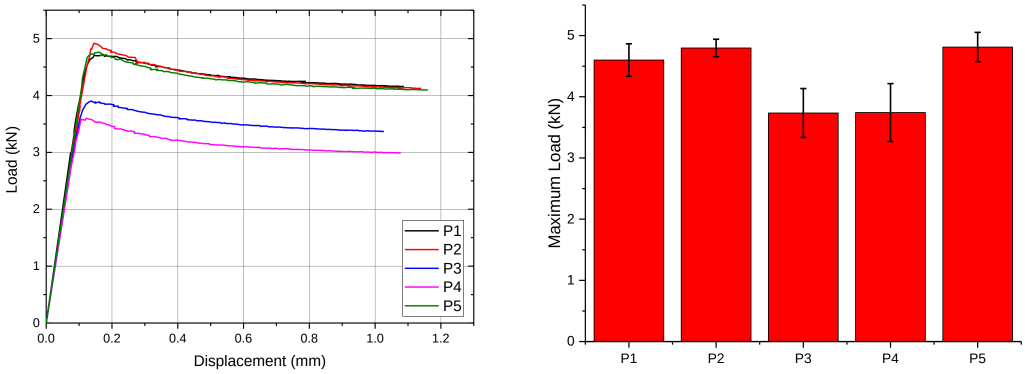


Fig. 13 The testing fixture for RAE compression test

In compression possible failure modes are by buckling, barreling, double barreling or by instability by softening. In this test the aim of the study was failure by buckling, thus a specimen with width to free length ratio of 0.4 was chosen (20.5mm width and 51mm free length).

Three specimens were tested for each condition and in Fig. 14.a load-displacement curves are presented: the samples were loaded until failure by buckling occurred. Analyzing the curves the maximum load that the sample withstood was identified and in Fig. 14.b the average value±1 standard deviation is presented.



a. b.

Fig. 14 Comparison of a. load-displacement and b. maximum loads in the test.

The compression behavior was similar: all samples which failed by buckling, yet the maximum load was found to be similar for samples P1, P2 and P5, while samples P3 and P4 showed lower values.

Sample P2, being practically cold worked, withstands the highest load, while samples P1 and P5 behave in a similar manner. The heated samples, P3 and P4, as expected, begin to buckle at lower loads.

3.6 Flexural testing

Flexural testing was performed on rectangular specimens using a 3 point bending fixture in accordance to *ASTM C1161-04: "Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature"* mounted on the Walter+Bai LFV 300 universal testing machine. The span length was 60mm and the rollers used were 25mm in diameter with the test speed of 1mm/min.

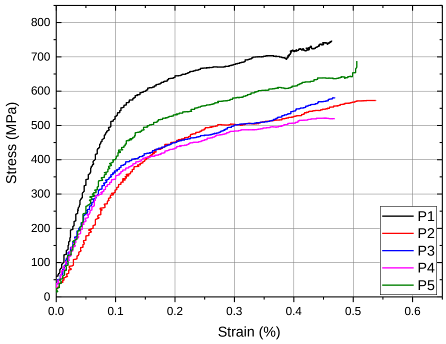


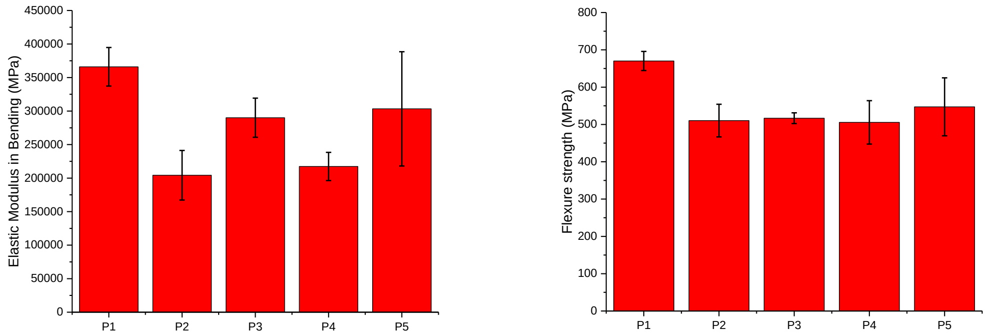
Fig. 15 Stress - strain curves in flexure

Three specimens were tested for each sample condition, in Fig. 15 representative stress - strain curves in bending are presented.

The sample behavior is ductile, yet given uneven strain distribution within the sample it can be seen that sample P1 is most rigid while sample P2 the least. The heated specimens (P3 and P4) show similar rigidity to the one straightened using the spotter (P5), while the cold worked sample (P2) was least rigid given its uneven surface (small dents that could not be straightened).

The elastic modulus in bending was determined according to *ASTM D790 -17:"Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials"* and the flexural strength was determined as the strength that corresponds to a 0.2% strain.

In Fig. 16 a comparison of the elastic modulus and flexure strength is presented.



a. b.

Fig. 16 Comparison of a. elastic modulus in bending and b. flexure strength

The elastic modulus in bending shows that the reference sample P1 has the highest value while the sample straightened with the spotter is second highest, but with a large data spread.

The flexural strength determined at 0.2% strain shows that sample P1 has the highest value, while sample P5 the second highest. All remaining specimens, P2, P3 and P4 have similar values that are lower than P5.

The mechanical behavior in bending of the specimens is again explained by sample structural inhomogeneity that leads to non uniform strain distribution [20].

4. Conclusion

The mechanical behavior of straightened auto vehicle body panels was studied in tension, compression and bending.

The results obtained by applying four straightening methods were compared with the characteristics of the original body panel to find which methods would assure best mechanical behavior and characteristics - this study was performed on small to medium surface area damage. It was estimated that using cold working for straightening the yield strength in tension can achieve, at best, 94% of the initial value, and its toughness can be as high as 95-96% of the original. In bending 76% of its initial flexural strength is expected, while in compression no statistically significant differences are expected from the reference value. When straightening is performed by heating 75-84% of initial yield strength is expected (with experienced personnel performing the procedures), 91-95% of the initial toughness and 76-78% of the initial flexural strength. In compression 78-82% of the initial performance can be achieved.

Temperature and heat affected surface area control are decisive in this process. Using induction heating a more precise and localized heating is possible. Using the spotter for straightening the repaired panel can achieve up to 89% of the initial yield strength in tension and 69% of its original toughness. In bending 89% of its original flexural strength can be achieved, while in compression a slight improvement, by 4-5% compared to an original panel can be expected.

From a mechanical perspective repairing procedures that did not involve heat yielded highest values, yet from a corrosion point of view these regions are most prone. Straightening by cold working (hammering) yields results that are more reproducible and repeatable than when using the spotter where the most unpredictable behavior was observed.

Acknowledgment

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